Chapter 1

Introduction to Quaternary Paleoseismology and Stratigraphy of the Yucca Mountain Area

By John W. Whitney, Emily M. Taylor, and Christopher M. Menges

Contents

Abstract

Eight faults with demonstrable Quaternary activity have been identified in and adjacent to the proposed repository site for the storage of high-level radioactive wastes at Yucca Mountain in southwestern Nevada. Data regarding fault geometry and displacements, ages and characteristics of closely associated Quaternary deposits, paleoearthquake-recurrence intervals, and fault-slip rates were collected principally from trenches excavated across faults or from cleaned-off natural exposures. Specific results of the large-scale geologic mapping of fresh exposures and the numerical dating of soils and other surficial deposits involved in Quaternary fault activity are discussed in succeeding chapters of this report.

Three measurements of fault displacement—individual, cumulative, and net cumulative—were used in recording faulting events. Surficial deposits were dated by two basic dating techniques: (1) U-Th-disequilibrium-series (U series) analyses of pedogenic carbonate-silica laminae and clast rinds, matrix soil carbonate, and rhizoliths; and (2) thermoluminescence analyses of fine-grained polymineralic material. Recurrence intervals between successive surface-rupturing paleoearthquakes were computed for each trench site on the basis of available numerical ages for the affected Quaternary deposits. Fault-slip rates were calculated by dividing the cumulative net slip (sum of all individual displacements) by the age of a specific faulted marker horizon.

Purpose and Scope of Paleoseismic Studies

Since the late 1970s, Yucca Mountain in southwestern Nevada (fig. 1) has been investigated by the U.S. Department of Energy as a geologic repository for the storage of high-level radioactive wastes. As part of an interdisciplinary site-characterization program (U.S. Department of Energy, 1988), a series of specific studies bearing on the location, extent, timing, and magnitude of Quaternary faulting within and adjacent to Yucca Mountain were conducted for the purposes of seismic-hazard assessment, seismic design of surface and subsurface facilities, and repository-performance evaluations and to satisfy regulatory licensing requirements. The history of Quaternary faulting and seismic activity within the proposed repository-site area provides essential information for the integrated safety analysis as required by the U.S. Nuclear Regulatory Commission (10CFR Part 60), which calls for the identification of potential geologic hazards and characterization of future faulting events. Relative to this requirement, paleoseismic data are especially critical to both deterministic and probabilistic seismic-hazard analyses, wherein faults, on the basis of their past history of surface ruptures and seismicity, are evaluated as to their potential for generating future earthquakes of a given magnitude and within a given time period.

During the 1980s, two sets of studies were conducted to identify faults with evidence of Quaternary surface ruptures. Preliminary mapping of Quaternary deposits around Yucca Mountain was completed at 1:48,000 scale (Swadley, 1983;

Swadley and Carr, 1987; Swadley and Parrish, 1988) and later refined by more detailed mapping at 1:12,000 scale (Swadley and Hoover, 1989a, b; Swadley and Huckins, 1989, 1990). During that period, Swadley and Hoover (1983) and Swadley and others (1984) also made a preliminary identification of faults with probable Quaternary activity. Subsequently, detailed examinations of the exposures of all faults in the Yucca Mountain area (fig. 1) were compiled by Simonds and others (1995), whose map then served as a basis for selecting those faults that either demonstrated evidence of Quaternary surface ruptures or were suspected of Quaternary activity and therefore required additional study with regard to paleoseismicity.

A detailed discussion of stratigraphic studies and the mapping of Quaternary deposits is presented in chapter 2, and fault descriptions are summarized in chapter 3. The results of paleoseismic studies for eight identified Quaternary faults—the Paintbrush Canyon, Bow Ridge, Stagecoach Road, Solitario Canyon (including Iron Ridge), Fatigue Wash, Windy Wash, and Southern and Northern Crater Flat Faults (fig. 2)—and for several other faults suspected of Quaternary activity in the immediate vicinity of Yucca Mountain are presented in chapters 4 through 11. Chapters 12 and 13 describe similar studies that were conducted on the Bare Mountain and Rock Valley Fault systems that lie 14 km west and 25 km southeast, respectively, of the proposed repository site (fig. 1). The combined paleoseismic event data as presented in the individual fault studies are used in chapter 14 to summarize the evidence for distributive surface ruptures on multiple faults during the past 100 k.y., which is an important consideration in evaluating future seismicity at Yucca Mountain.

Plates, figures, and tables are numbered consecutively throughout this report for convenience in cross-referencing, and a combined reference list is provided at the end.

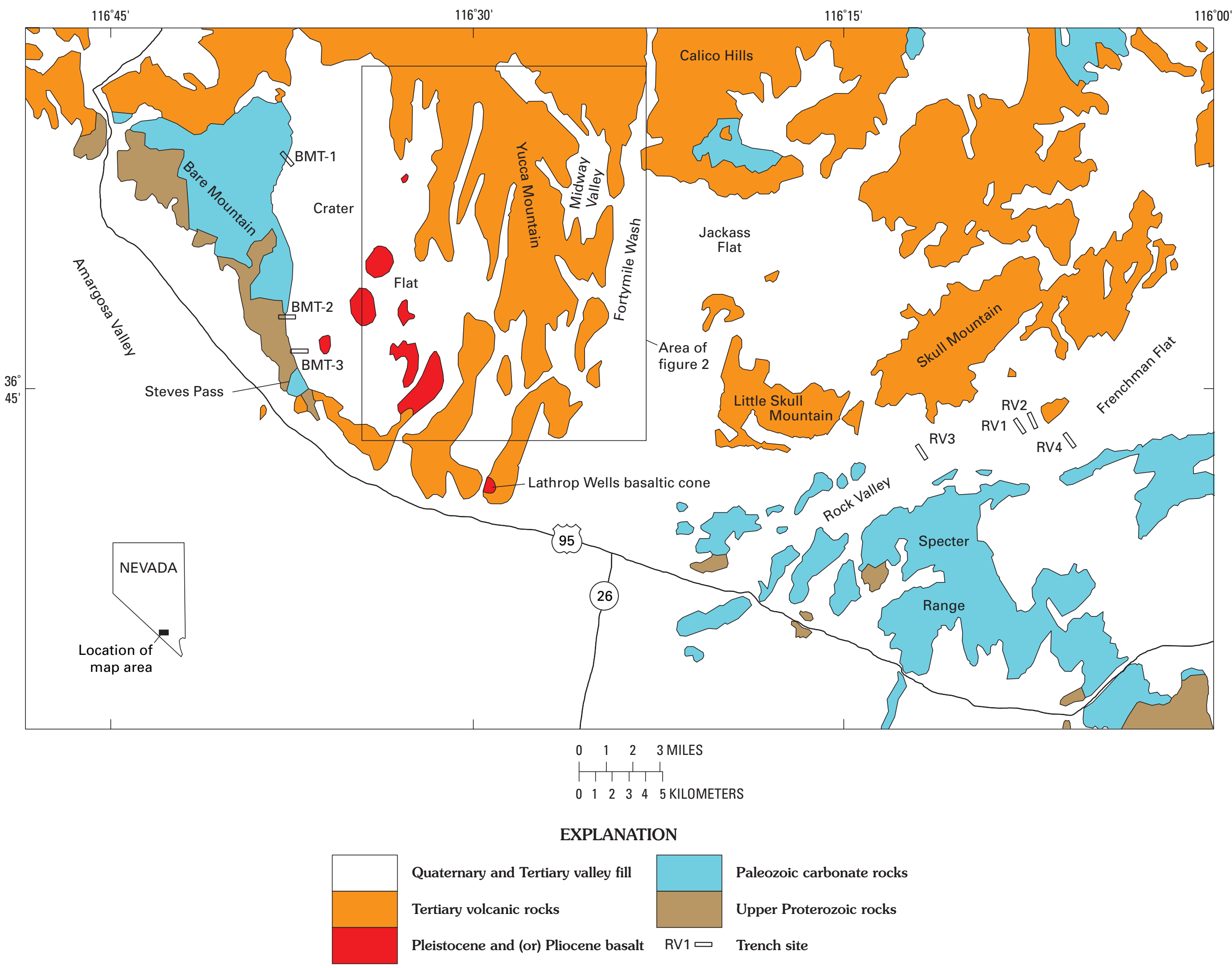

Figure 1. Southwestern Nevada, showing location of Yucca Mountain area, geographic features, general distribution of major rock types, and locations of trenches and other sites outside area of figure 2.

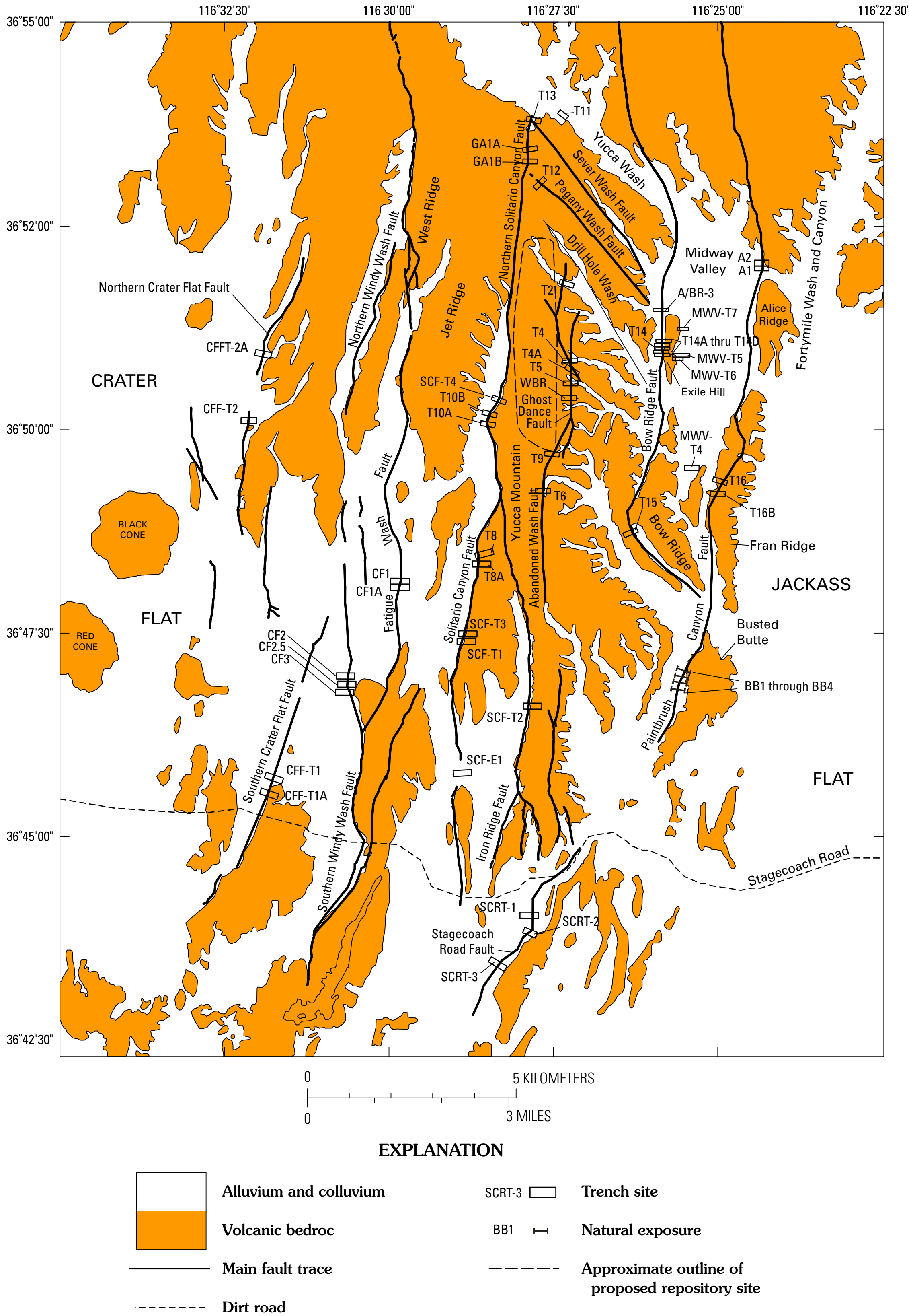

Figure 2. Index map of Yucca Mountain area, southwestern Nevada, showing locations of major faults and trench sites. All faults (solid lines) include segments that either cut or are interpreted to extend beneath Quaternary deposits. Adapted from Simonds and others (1995) and Day and others (1998a). Dashed outline, area of proposed repository site for storage of high-level radioactive wastes.

Table 1. Trench excavations across faults in the Yucca Mountain area, southwestern Nevada.

[See figures 1 and 2 for locations. References: Rpt, this report; SHR, Swadley and others (1984); T, Taylor and Huckins (1995); W, Whitney and others (1986). Modified?, statement whether original excavation was significantly modified: N, no; Y, yes. Logged?, statement whether trench walls were logged or mapped: N, no; Y, yes. Method, technique used to log excavation: MG, manual gridding; na, not applicable; Ph, photogrammetry; S, sketch log; Th, theodolite. Sampled geochrologically?, statement whether trench site was sampled for geochronologic analyses as part of present study. Fault exposed?, statement whether a fault is present in bedrock and (or) Quaternary deposits in trench: N, no; Y, yes. Fault exposed?, statement whether evidence was observed for Quaternary faulting or deformation: F, surface displacement on fault; Fr, fractures in Quaternary deposits that may or may not be associated with surface rupture on fault; I, indeterminate faulting, generally of unknown age only in bedrock; N, none. Report?, statement whether trench is described in this report: N, no; Y, yes]

Trench	Reference	Modified?	Logged?	Method	Sampled geochronologically?	Fault exposed?	Quaternary deformation?	Report?
Paintbrush Canyon Fault								
A1	SHR, rpt	Y	Y	S, Th	Y	Y	F	Y
A2	SHR	N	N	S	N	N	N	N
MWV–T3	rpt	N	N	na	N	N	N	N
MWV–T4	SHR, rpt	Y	Y	S, MG	Y	Y	F	Y
T16	SHR	N	Y	S	N	N	N	N
T16B	SHR	N	Y	S	N	N	Fr	N
BB–1	rpt	N	Y	Ph	Y	Y	F	Y
BB–2	rpt	N	Y	Ph	N	Y	F	N
BB–3	rpt	N	N	na	N	Y	F	N
BB–4	rpt	N	Y	Ph	Y	Y	F	Y
Bow Ridge Fault								
A–BR/3	rpt	N	Y	MG	N	N	N	N
T14	SHR, T	Y	Y	S, Ph	N	Y	F	Y
T14A	T	N	N	na	N	Y	I	N
T14B	T	N	N	na	N	Y	I	N
T14C	T, rpt	N	Y	MG	Y	Y	F	N
T14D	T, rpt	Y	Y	S, MG, Th	Y	Y	F	Y
T15	SHR	N	N	na	N	Y	I	N
Exile Hill Fault								
MWV–T5	rpt	N	Y	MG	Y	Y	Fr	N
MWV–T6	rpt	N	Y	MG	N	Y	Fr	N
MWV–T7	rpt	N	Y	MG, Ph	Y	Y	N	Y
Ghost Dance Fault								
T2	SHR, rpt	Y	Y	S, Th	Y	N	N	Y
T4	SHR, rpt	Y	Y	S, Th	N	N	N	Y
T4A	rpt	N	Y	Th	Y	N	N	Y
T5 (Antler Pavement)	rpt	N	Y	Th	N	Y	N	N
WBR	rpt	N	Y	Th	Y	Y	Fr	Y
Abandoned Wash Fault								
T9	SHR	N	Y	S	N	N	N	N
T6	SHR	N	Y	S	N	N	N	N
Pagany Wash Fault								
T12	SHR, rpt	N	Y	S	N	Y	N	N

Table 1. Trench excavations across faults in the Yucca Mountain area, southwestern Nevada—Continued

Trench	Reference	Modified?	Logged?	Method	Sampled geochronologically?	Fault exposed?	Quaternary deformation?	Report?
Sever Wash Fault								
T11	SHR	N	Y	S	N	N	N	N
Stagecoach Road Fault								
SCR–T1	rpt	N	Y	Ph, MG	Y	Y	F	Y
SCR–T2	rpt	N	N	na	N	N	N	N
SCR–T3	rpt	N	Y	Ph, MG	Y	Y	F	Y
Solitario Canyon Fault								
T13	SHR	N	Y	S	N	N	N	N
GA1A	SHR, rpt	N	Y	S	N	Y	F?	N
GA1B	SHR, rpt	N	Y	S	N	Y	F?	N
Ammo Ridge	rpt	N	N	na	N	Y	F?	N
SCF–T4	rpt	N	Y	Th	N	Y	F	Y
T10A	SHR	N	Y	S	N	N	N	N
T10B	SHR	N	Y	S	N	Y	I	N
T8	SHR, rpt	Y	Y	S, Th	Y	Y	F	Y
SCF–T3	rpt	N	Y	Th	Y	Y	F	Y
SCF–T1	rpt	N	Y	Th	Y	Y	F	Y
SCF–E1	rpt	N	N	na	N	Y	F	N
Iron Ridge Fault								
SCF–T2	rpt	N	Y	Th	N	Y	F	Y
Fatigue Wash Fault								
CF1	SHR, rpt	Y	Y	S, Ph	Y	Y	F	Y
CF1A	rpt	N	Y	S	Y	Y	F	Y
Windy Wash Fault								
CF2	SHR, W, rpt	Y	Y	S, MG	Y	Y	F	Y
CF2.5	W, rpt	N	Y	MG	N	Y	F	Y
CF3	SHR, W, rpt	Y	Y	S, MG	Y	Y	F	Y
Southern Crater Flat Fault								
CFF–T1	rpt	N	Y	Th	Y	Y	F	Y
CFF–T1A	rpt	N	Y	Th	Y	Y	F	Y
Northern Crater Flat Fault								
CFF–T2	rpt	N	N	na	N	N	N	N
CFF–T2A	rpt	N	Y	Ph	Y	Y	F	Y

Trenching Activities

Typically, the Quaternary faults in the Yucca Mountain area (fig. 1) show little evidence of historical activity, and so they require a systematic collection of data on (1) fault geometry; (2) characteristics and ages of surficial deposits closely associated with each fault; (3) number, amounts, and ages of individual surface displacements; (4) paleoearthquake-recurrence intervals; and (5) fault-slip rates (Allen, 1986; Schwartz, 1988; dePolo and Slemmons, 1990; Reiter, 1990; Coppersmith, 1991). Such data were collected principally from trenches that were excavated across faults to provide fresh exposures of Quaternary deposits and their stratigraphic and structural relations (see Hatheway and Leighton, 1979).

Some 50 exploratory trenches have been excavated, or natural exposures cleaned, since the early 1980s in the vicinity of Yucca Mountain (fig. 2; table 1). In all, 41 of these trenches and natural exposures are associated with the eight proximal faults with demonstrable Quaternary activity. Most excavations are located on the surface traces of those faults, although a few are located across the projections of a fault through undisturbed alluvium or a geomorphic surface. The rest of the trenches were located across mostly bedrock faults in the central Yucca Mountain area (fig. 1), such as the Ghost Dance, Abandoned Wash, and Pagany Wash Faults, that exhibit no surface evidence for Quaternary activity, as indicated by the mapping of Simonds and others (1995). These trenches were designed to provide additional information on possible Quaternary activity by excavating fault traces where they project beneath Quaternary deposits and surfaces.

A total of 25 trenches contain clear evidence for Quaternary activity on their respective faults in the form of surficial deposits that are displaced or deformed across the fault trace (table 1). The other trenches lack such evidence; either undisturbed deposits bury the fault zone, or, in some places, no fault is exposed in Quaternary deposits that overlie the fault zone as projected from nearby outcrops of bedrock, indicating no discernible Quaternary activity. These relations provide minimum constraints on the presence and (or) recency of displacements within such deposits on a particular fault.

The trenching operations were conducted in three phases that are tied to different elements of the Yucca Mountain site-characterization studies. During the first phase, a group of trenches were excavated in the early 1980s as part of reconnaissance studies of known faults. Most trenches were excavated by bulldozer, and generalized sketch logs were prepared and preliminary results reported by Swadley and others (1984). During the second phase, additional localized work was conducted in the middle to late 1980s at several sites, including trenches T14, CF2, and CF3 (fig. 2; Whitney and others, 1986; Taylor and Huckins, 1995). Existing trenches were modified, and some additional trenches were excavated by backhoe (table 1). Complete logs were compiled for selected trenches by using photogrammetric and standard-grid techniques. During the third phase, trenching investigations were resumed in 1992 when many existing trenches were modified, backhoes were used to excavate new trenches, and several natural exposures of faults were enhanced by extensive cleaning. Most of the trenches with demonstrable Quaternary faulting were subsequently logged by various techniques, including standard manual grid, theodolite, and photogrammetric. Most of the paleoseismic data and interpretations presented in this report were collected and developed during the third phase of trenching operations.

Trenches (fig. 2) were located on the basis of several criteria. Many trench sites were identified initially by a combination of ground reconnaissance and photointerpretative mapping on aerial photography. Where possible, a trench was located along a fault scarp or other geomorphic expression of a fault zone where evidence of Quaternary activity had been observed—generally where the fault trace crosses surficial deposits associated with such geomorphic surfaces as alluvial fans, fluvial terraces, sand ramps, or hillslope colluvial aprons. Commonly, a trench was located on a younger geomorphic surface so as to better record the most recent activity on a given fault. Trenches were located on older geomorphic surfaces to provide a record of earlier faulting for the purposes of long-term paleoseismic analyses, such as recurrence-interval calculations.

Some trenches were located across various types of lineament as mapped on aerial photographs where a fault crosses or projects beneath a Quaternary surface. Many such lineaments are subtle features defined by tonal contrasts or vegetation alignments. The purpose of these excavations was to determine whether mappable surface lineaments are related to tectonic features in the subsurface.

The dimensions and configurations of trenches range from 3 to 300 m in length, from 1.5 to 10 m in width, and from 2 to 10 m in depth. Most are 10 to 50 m long, 2 to 4 m wide, and 2.5 to 3 m deep. Orientations are mainly east-west, approximately perpendicular to the predominantly north-south strike of most faults. Bulldozer trenches generally have two vertical walls, whereas backhoe trenches commonly have one vertical wall on the south side opposite a benched wall on the north. The different configurations were determined by Occupational Safety and Health Administration regulations pertaining to trenches of a particular width. A benched configuration, for example, was used in 3-m-deep backhoe trenches because it removed the need for emplacement of shoring, which makes detailed logging more difficult. Generally, only vertical walls were logged because they are most amenable to accurate mapping and best preserve the geometric relations of stratigraphy and structure.

Methods

Logging of trenches and exposures after 1984 followed the same basic procedures. The walls were first cleaned to allow identification and mapping of fault deformation and the stratigraphy and soil relations of surficial deposits. Structures, stratigraphic contacts, and soil horizon boundaries were identified and flagged, and the relative positions of flagged features were measured and plotted on trench logs, using one of the three techniques outlined below. Deformational features, stratigraphic units, and soils were mapped and described; and where possible, critical stratigraphic units and soils related to faulting events were sampled for geochronologic dating (see chap. 2).

Detailed logs were assembled from the mapped trench exposures according to one of three techniques:

1. The standard manual gridding technique uses a grid with a level line that is constructed on the trench wall (Hatheway and Leighton, 1979). Flagged features are measured relative to this reference grid and plotted to scale on graph paper.
2. The theodolite technique uses a theodolite to precisely survey the position of each flagged point on the trench wall. The surveyed points are plotted to scale, and then lines are drawn between the points to define the mapped structural, stratigraphic, and soil features.
3. The close-range photogrammetric technique uses a series of photographs of the trench walls that are taken with a prescribed amount of stereographic overlap (Fairer and others, 1989; Coe and others, 1991). The mapped features are drawn on these photographs in the field. The surveyed positions of control points in the photographs are then used to construct a rectified stereomodel, and an accurately scaled log is drawn with a stereoplotter.

The resulting logs and field data from trenches along a given fault were integrated to derive paleoseismic interpretations. Foremost among such interpretations are the stratigraphic positions, displacements, and ages of surface ruptures associated with paleoearthquakes on the fault zone (Schwartz, 1988; Nelson, 1992). Individual surface ruptures were identified in trench-wall exposures by using several criteria, including (1) abrupt increases in the amount of offset or backtilting of marker horizons or stratigraphic units across the fault; (2) recognition of buried deposits or features, such as scarp-derived colluvial wedges or debris-filled fissures, that commonly are associated with surface ruptures (Nelson, 1992); and (3) upward termination of fractures, fissures, or shears at the base of a stratigraphic unit. Commonly, uncertainties arise in identifying at least a few of the surface ruptures at a given trench site because of ambiguities and complexities in structural and stratigraphic interpretations.

Three measurements of fault displacements (individual, cumulative, and net cumulative) were used in the recording of faulting events. Where possible, individual dip-slip displacements associated with each faulting event were determined directly by measuring the displacement of marker horizons across the fault and then subtracting the offset related to any later events identified higher in the stratigraphic section. This procedure could not be used, however, if the same marker horizons are not present on opposite sides of the fault. At some trench sites, for example, upper Quaternary deposits on the hanging-wall block are faulted against older deposits or bedrock on the footwall block from which younger deposits have been stripped off by erosion. Several different methods were used in those situations. At some trench sites, single-event offsets were based on the thickness of fault-related colluvial wedges, resulting in minimum estimates that are commonly 50 to 80 percent of the actual surface displacement (Swan and others, 1980; Machette and others, 1992; Nelson, 1992). An alternative method involved measurement of the vertical separation between a displaced event horizon in the hanging-wall block and the stratigraphically highest, but older, faulted unit on the footwall block to determine the total offset. Displacements per event were then calculated by subtracting from this measurement the offsets related to individual faulting events that are identifiable at stratigraphically higher event horizons in the hanging-wall blocks. A similar technique used the stratigraphic thickness of deposits between successive event horizons on the hanging-wall block as a maximum estimate for the displacement associated with the stratigraphically lower event. The uncertainties inherent in all of these methods are accounted for in the range of reported displacements.

Cumulative dip-slip displacements were determined analogously either by measuring the total offset along the fault of a given marker horizon or stratigraphic unit or, where correlative units are absent across the fault, by summing the thicknesses of all fault-related colluvial wedges at and above the reference unit. Cumulative dip-slip displacements were adjusted in two ways to determine cumulative net-slip displacements: (1) normal-oblique slip was calculated for any trench site that contains possible slip indicators, such as slickenlines on bedrock shears that are related to Quaternary deformation, or, less reliably, striations on carbonate coatings within fault zones; and (2) at some trench sites, displacement of units that were deformed near the main fault zone, either by backtilting toward the fault surface and (or) by development of antithetic grabens, was measured and evaluated. The effects of this secondary deformation were removed by projecting displaced units into the fault zone from undeformed sections of the hanging wall and footwall before measuring displacements on the main fault zone. All measurement uncertainties are propagated through the derivations of both cumulative and net displacements.

Recurrence intervals—the time periods between successive surface-rupturing paleoearthquakes—were computed for each trench site by using all available dated deposits that could be related to faulting events. Individual recurrence intervals were determined where adequate age control exists to isolate the relative timing of pairs of successive faulting events. This procedure is most precise where the dated units are colluvial wedges or fissures that can be associated closely with faulting events, although such conditions are rare. More commonly, dated deposits were formed at some unknown time between successive faulting events and so simply bracket two or more events. For such events, average recurrence intervals were calculated by dividing the time between the age constraints by the number of possible intervals between events. Uncertainties in both the dating of stratigraphic units (reported as $\pm 2\sigma$ analytical-error limits) and the number of possible faulting events are incorporated into the reported ranges of recurrence intervals.

Fault-slip rates were calculated by dividing the cumulative net slip by the age of a specific faulted deposit or event horizon. Most slip rates are averages derived from the oldest faulted units with adequate age control, which typically are displaced by two or, commonly, three or more faulting events. The range of slip rates accounts for uncertainties in both age control and displacement.

Age controls for both faulted and unfaulted stratigraphic units and soils were provided by several techniques, as discussed in chapter 2. A general chronologic framework was provided by the composite Quaternary chronosequence of surficial deposits in the Yucca Mountain area from previous studies (Taylor, 1986; Hoover, 1989; Wesling and others, 1992; Lundstrom and others, 1993). Samples were collected from mapped lithologic units at all trench sites to provide direct geochronologic control for paleoseismic investigations at Yucca Mountain (Paces and others, 1994; J.B. Paces, written commun., 1995). The studies employ two basic dating techniques (1) U-Th-disequilibrium-series (U series) analyses of pedogenic carbonate-silica laminae and clast rinds, matrix soil carbonate, and rhizoliths (carbonate-replaced root casts); and (2) thermoluminescence analyses of fine-grained polymineralic material.

Trenches with No Quaternary Deformation

As noted previously, some trenches did not reveal evidence of Quaternary faulting (table 1). Typically, undisturbed stratigraphic units in those trenches overlie the fault trace in bedrock, or no fault is present in Quaternary deposits that are situated above the projection of the fault from adjacent outcrops. The absence of such evidence, however, still provides important information that helps delimit the extent and timing of Quaternary faulting activity. At some trench sites, for example, the presence of undeformed deposits constrains the lateral (along strike) extent of surface ruptures related to Quaternary activity elsewhere on a particular fault. The absence of evidence for faulting may also provide information on the presence and degree of activity on subsidiary strands of potentially wide and complex fault zones. Commonly, the trenches furnish minimum age constraints on the most recent fault displacements, as determined by the ages of the oldest undisturbed Quaternary deposits. A few trenches lack evidence of Quaternary deformation because they are not properly located on the fault trace. Some of the more important individual trenches that did not intersect Quaternary faults are summarized below.

Paintbrush Canyon Fault

Two trenches at the north end of Alice Ridge near Yucca Wash (fig. 2) expose no fault zone or show no evidence of Quaternary deformation in fluvial-terrace deposits. A Quaternary surface rupture on a distinct shear zone of the Paintbrush Canyon Fault is present only in trench A1 at this site. One of the trenches without faults, A2, was excavated across upper Pleistocene terrace gravel (unit Qa3; see chap. 2; fig. 3; tables 2, 3) on the southward projection of the fault trace from a bedrock outcrop to the north (Swadley and others, 1984). This relation indicates either that the fault does not cut material of that age or that the fault trace lies farther east and was not intersected by the trench. Surface rupture possibly did not extend northward from the nearby trench A1 to the south. The other trench, MWV–T3 (not shown in fig. 2), was excavated on a vegetation lineament formed in middle Pleistocene terrace deposits (unit Qa1) west of the main trace of the fault exposed in trench A1. The absence of a fault in trench MWV–T3 indicates that the zone of Quaternary surface rupture is narrow and that the fault is exposed to the east only in trench A1 at the base of Alice Ridge.

Faulting is also absent in two trenches excavated in middle to upper Pleistocene sand-ramp deposits in a saddle at the base of Fran Ridge (fig. 2; Swadley and others, 1984). The north end of the southern section of the Paintbrush Canyon Fault zone was mapped through this area (Simonds and others, 1995). No fault was intersected in trench T16, probably because the trench is located west of the main fault trace. Trench T16B, which contains only carbonate-coated fractures, may not have been excavated deep enough to expose the main fault trace. Alternatively, the zone of Quaternary surface rupture may not have continued this far northward on the southern section of the fault.

Bow Ridge Fault

Trench A/BR–3 (figs. 2, 8) was located on a vegetation lineament in the upper Pleistocene alluvial fan that lies on the northward projection of the Bow Ridge Fault from the complex of trenches (T14, T14A–T14D) on the west side of Exile Hill. The absence of faulting or Quaternary deformation is present in the fan gravel exposed in the trench indicates that either the subsurface fault trace lies west of the trench or surface rupture on the fault probably did not continue northward of Exile Hill.

The Bow Ridge Fault is exposed only in bedrock in two shallow trenches (trenches T14A, T14B, fig. 2) north of trench T14 at the base of Exile Hill. Another trench (trench T15; see Swadley and others, 1984) at the base of Bow Ridge on the southern section of the fault zone and online with a nearly 2-m-high bedrock scarp likewise did not expose Quaternary deposits.

Exile Hill Fault

The Exile Hill Fault displaces buried bedrock at the base of the eastern margin of Exile Hill at the west edge of Midway Valley (figs. 1, 2; see chap. 4). Trenches MWV–T5, MWV–T6, and MWV–T7 (fig. 2) reveal that an overlying thin veneer of mostly upper Pleistocene colluvium (units Qa3, Qa4; see chap. 2) is fractured locally but not displaced along the fault. Those relations, which were established during highly detailed logging of the trenches, resulted in placing a minimum age constraint for the most recent surface rupture on the Exile Hill Fault. Determining a minimum date for this faulting event is important for the placement and design of surface facilities at the proposed repository site.

Ghost Dance Fault

The Ghost Dance Fault is a down-to-the-west bedrock normal fault that trends north along the east side of the proposed repository block for about 7 km (figs. 2, 4; Day and others, 1998a). Thus, this fault has been the subject of extensive investigations to determine whether any Quaternary surface displacements occurred along its trace. As described in chapter 6, the fault is well exposed in Tertiary volcanic rocks, but no Quaternary activity is indicated in the intersecting trenches.

Abandoned Wash Fault

The Abandoned Wash Fault (fig. 2) is a north-striking fault that may represent a southwestern splay of the Ghost Dance Fault (Day and others, 1998b). For much of its length, the Abandoned Wash Fault occupies a narrow valley floored with uppermost Pleistocene to Holocene alluvium. These deposits are tectonically undisturbed in trench T6 (Swadley and others, 1984), which lies along the projection of the fault across the valley floor. Similar undisturbed alluvial and colluvial deposits are exposed in trench T9, which is located in a small valley north of the canyon containing trench T6 (Swadley and others, 1984); however, trench T9 may not be properly located to intersect the fault (Simonds and others, 1995).

Drill Hole Wash, Pagany Wash, and Sever Wash Faults

The Drill Hole Wash, Pagany Wash, and Sever Wash Faults (fig. 2) strike northwest at the northeast corner of Yucca Mountain (fig. 1) and for much of their lengths occupy similarly trending valleys (Day and others, 1998a). The Drill Hole Wash Fault is almost entirely concealed by alluvial deposits, although strands are exposed for short distances in bedrock. Trench T2 is located in the southern arm of the wash but was sited to intersect a north-trending splay of the Ghost Dance Fault rather than the Drill Hole Wash Fault farther north. The Pagany Wash Fault is well exposed in bedrock in trench T12, which is located where the fault transects a broad ridgecrest (Swadley and others, 1984). Thin colluvial deposits with argillic and calcic soil horizons indicative of at least a late Pleistocene age overlie the fault trace with no displacement. Thus, evidence for late Quaternary activity on the Pagany Wash Fault was not observed. Trench T11 was excavated in upper Pleistocene to Holocene alluvium and colluvium on a strand of the Sever Wash Fault as projected southeastward from bedrock outcrops into the alluvium-floored valley bottom of Yucca Wash (Swadley and others, 1984). No fault or evidence of any Quaternary deformation was observed in the trench, although it may not be located accurately above the poorly constrained surface projection of the fault.

Stagecoach Road Fault

Trench SCR–T2 (fig. 2) was excavated across a subtle topographic break and tonal photolineament located a short distance east of the Stagecoach Road Fault trace. No Quaternary faults are evident in the lower to middle Pleistocene surficial deposits exposed in the trench; thus, the features observed at the surface before trenching are nontectonic. This absence of fault deformation in trench SCR–T2 indicates that Quaternary activity on the Stagecoach Road Fault was restricted to the main fault zone, which was intersected in trench SCR–T1 to the west (see chap. 5).

Solitario Canyon Fault

Trench T13 (fig. 2) is located toward the north end of the Solitario Canyon Fault along a northward projection of the fault trace in bedrock beneath the alluvium of Yucca Wash (Swadley and others, 1984). No fault or evidence of any Quaternary deformation was observed in the upper Pleistocene and Holocene deposits exposed in the trench. Either the trench missed the fault trace, or the late Quaternary surface rupture that is evident along the Solitario Canyon Fault farther south (see chap. 7) probably did not continue so far northward.

Trenches T10A and T10B (fig. 2) were excavated across an eastern splay of the fault within Solitario Canyon (Swadley and others, 1984). No fault is evident in the lower to middle Pleistocene alluvium and colluvium exposed in trench T10A. Either the trench may not have been properly located with respect to the fault zone, or no Quaternary deformation has occurred on that splay of the fault. Improper location seems the more likely explanation because similar deposits are displaced by a fault zone in trench T10B, which is located on the same splay. Upper Pleistocene and Holocene deposits are not tectonically disturbed in either trench, indicating that no late Quaternary activity has occurred on the eastern strand of the fault. Late Pleistocene surface ruptures, however, are observed in trench SCF–T4 (fig. 2), which is located on another fault strand to the east.

Northern Crater Flat Fault

Trench CFF–T2 (fig. 2) was excavated across a weakly defined photolineament on a middle Pleistocene to upper Pleistocene alluvial fan that extends across the projected trace of the Northern Crater Flat Fault between bedrock outcrops to the south and north. The lineament is the only apparent expression of the fault zone on the alluvial-fan surface. No fault or evidence of Quaternary deformation was observed in the upper Pleistocene alluvium exposed in the trench, although a fault with late Quaternary displacements is evident in older Pleistocene alluvium in trench CFF–T2A several kilometers to the north (see chap. 11). Absence of faulting in trench CFF–T2 indicates either that (1) a gap exists in surface displacements in the vicinity of the fan, (2) surface rupture terminates between the two trenches, or (3) no faulting event has occurred since the accumulation of Quaternary deposits at the trench site.